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The Development and Use of Pitfall and Probe Traps for Capturing Insects in Stored Grain

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ABSTRACT: The development and use of pitfall and probe traps for capture of insects in bulk-stored grain are outlined. Unbaited traps are effective in detecting infestations and they detect a large number of species compared with grain-sampling devices. The effectiveness of the traps is related to temperature, trapping period, and grain moisture content; and traps are less reliable for detecting insect species that are less mobile, have a non-uniform distribution in grain, feed within kernels, or can escape from the traps. Comparisons are given between effectiveness of probe traps and grain sampling for detecting insects, and experience using probe traps in stored grain is reported.

The use of traps is a relatively new method of detecting insects in bulk-stored grain (Loschiavo and Atkinson, 1967). The traps, whether simple pitfalls at the grain surface (Watters and Cox, 1957) or probe traps under the grain surface, offer numerous advantages (Loschiavo and Atkinson, 1973) over the standard sampling procedure of collecting small volumes of grain and sifting or incubating them, or extracting insects in Berlese funnels. The traps are simple to use, are escape-proof to many species, and provide a mechanism for continuous monitoring for stored-product insects. Monitoring over time gives a quick indication of population growth without taking grain samples. Adult beetles are captured live in the traps. Detecting low insect densities, the traps can give early warning of potential insect problems (Wright et al., 1988). The success of control measures can also be accurately assessed (Pinniger, 1988).

The traps have several advantages over the standard sampling procedures, notably the sensitivity of insect detection. However, there are several potential problems associated with the use of the traps. Their sensitivity may be a disadvantage in countries which have a legally-defined zero tolerance for all live insects in export grain such as Canada or Australia. This problem may often be less severe in countries such as the United States which at present have a defined economic threshold for insects in stored grain, which is based on grain samples. Relating numbers of insects captured in traps with absolute numbers per volume of grain needs to be addressed (Lippert and Hagstrum, 1987). Other problems related to interpreting numbers of insects captured and use of the traps will also be discussed in this review.

Probe traps offer an extremely useful tool in scientific research and surveys,

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and can be used effectively by farmers and grain managers to plan management tactics. For example, the type of species present can reflect the condition of the grain. The presence of only fungus-feeding beetles will dictate different actions by managers than will infestations by grain-feeding insects. The conditions that affect capture of particular species also need to be defined. Whether these traps will ever be accepted by governmental regulatory agencies concerned with export grain quality remains to be seen.

The following review covers some early uses of pitfall traps, the development of probe traps, advantages and disadvantages of probe traps, and experience obtained by using them in the field.

Pitfall Traps

Pitfall traps have been used widely to capture soil-inhabiting insects (Southwood, 1978). These traps can logically be used in bulk-stored grain for capturing insects active on the grain surface. Watters and Cox (1957) placed empty beakers and beakers containing water in wheat in farm granaries, grain elevators and columns of wheat in the laboratory. Except for psocids and mites, most insects were found more often in water traps than in grain samples. Also, the number of granary weevils, *Sitophilus granarius* L. and rusty grain beetles, *Cryptolestes ferrugineus* (Stephens) in the traps was inversely related to moisture content of the grain. The advantages of the water trap are: a) insects from surrounding areas are concentrated in the trap, and some species are attracted to the water, which also prevents them from escaping; b) no special equipment is needed; c) traps are easy to examine; and d) the method is more reliable than standard sampling techniques. Disadvantages are: a) only insects at the grain surface are captured; b) fewer insects occur at the grain surface in cold weather; and c) grain can easily be spilt into the trap.

Wright and Mills (1985) tested plastic cups (7 cm diam × 9 cm deep) against trier samples of corn and perforated plastic probe traps in bins (1.3 metric tons) with known population densities of red flour beetle, *Tribolium castaneum* (Herbst) (0.5, 1.0, 2.0 and 4.0 insects/kg). The plastic cups were coated with a fluorocarbon resin dispersion (Teflon®) on the inner edge and placed with the lip of the cup at the grain surface. The corn was sampled at 4-day intervals with a standard grain trier after the plastic cups and probe traps (8 cm below the surface) were carefully removed.

More *T. castaneum* were captured in cups and probe traps than from grain samples. At the lowest densities (0.5 and 1.0 insects/kg), the cup consistently captured 3 times the number of insects/kg compared to the grain trier. When densities were increased to 2.0 and 4.0 insects/kg, the cups captured fewer *T. castaneum* than the other two sampling techniques (Table 1). Insect counts from probe traps placed in the bottom of the bins showed that at the two higher densities the dispersion pattern of *T. castaneum* had changed from 90% of the adults in the top half of the bin (60 cm) to about 70%, with an increase of 20% in the bottom of the bin. This change in dispersion pattern at higher densities affected the number of insects available for pitfall cups at the grain surface. Other insects more likely to be found in the bottom of bins of corn, e.g., *Cryptolestes, Sitophilus* (Wright and Mills, 1985) were not well represented in pitfall cups.

Plastic beer-mug pitfall traps have also been used in stored grain and compared

Table 1. Captures of *Tribolium castaneum* (Herbst) in corn by three sampling methods (Wright and Mills, 1985).

Method[a]	Insects/kg in the bin 0.5	1.0	2.0	4.0
Grain trier	0.5	0.8	3.9	6.2
Cup (surface pitfall)	1.5	2.6	2.9	5.1
Probe trap (3.8-mm holes)	4.9	12.5	17.6	32.3

[a] Average of 5 triers or 5 traps or 5 cups (×3 bins).

with probe traps (Pinniger et al., 1986; Cogan and Wakefield, 1987; Pinniger, 1988). With the use of clean wheat in the laboratory (Pinniger et al., 1986) and a coating of Fluon® (liquid teflon, polytetrafluoroethylene) on the inner rim of the pitfall traps, more adults of sawtoothed grain beetles, *Oryzaephilus surinamensis* (L.) and *S. granarius* were captured in pitfall traps than in probe traps after 3 days. Similar results were found under field conditions. It was suggested that the use of both pitfall traps at the grain surface and probe traps under the grain surface would increase the chances of detecting insects about 10 times over spear sampling.

A modified pitfall trap (tube trap) for use in bags of cereals (Ashman, 1970; Hodges et al., 1985) has been used. This trap is a glass tube covered on the outside with filter paper and inserted vertically through small holes in bags of cereal. Generally, this type of trap works well only for adults of the red flour beetle which climb the outside of the trap, and it is inferior to other forms of traps.

A modification of a pitfall trap for use at the bottom of a grain bulk rather than at the top was made by Loschiavo (1974a) in railroad boxcars (Fig. 1). The trap was designed because probe traps could not be used effectively inside a boxcar because any protruding portions would be damaged during manual or automatic unloading of the grain. Two traps were installed in the floor of each boxcar. Five cars in 1972 and 25 cars in 1973, in regular service in western Canada, were monitored throughout the summers when they reached terminal elevators in Thunder Bay, Ontario; Churchill, Manitoba; or Vancouver, British Columbia. In 1973, a probe trap was attached to the rear wall of the cars, 150 cm above the floor. More insects were caught in the pitfall traps than in the probe traps, possibly because of a) rocking of the car during transit which produced a sifting action; and b) the positive geotaxis of some species of insects which move downward in a bulk of grain. In 1972, *C. ferrugineus* were trapped in 8 of 42 carloads of grain and *Cryptophagus* spp. in 2 loads. In 1973, 148 carloads of grain were moved and in 30 loads *C. ferrugineus* were trapped and in 93 loads fungus beetles were trapped. The mean number of insects per trap was only 1.2, reflecting low densities. The Canadian Grain Commission typically detects *C. ferrugineus* in no more than

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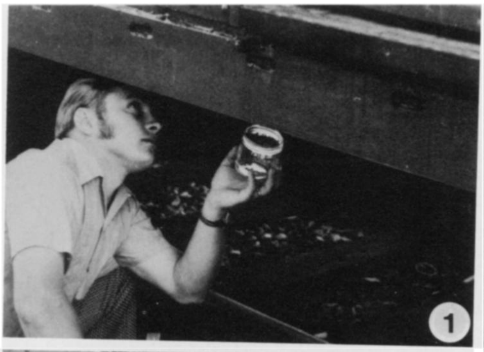
Fig. 1. Pitfall traps placed in the bottom of grain-carrying boxcars in western Canada. Top: 1) Placing glass container below floor; 2) view from below of a container in position; 3) view from above of the location of a trap in the floor; 4) close-up view of a trap surface. Bottom: 1) View of a boxcar; 2) placing a plastic container below the floor; 3) view from below of a trap container in the floor; 4) view from above of a trap location; 5) view of a probe trap fastened to the interior wall at the brake end of a boxcar.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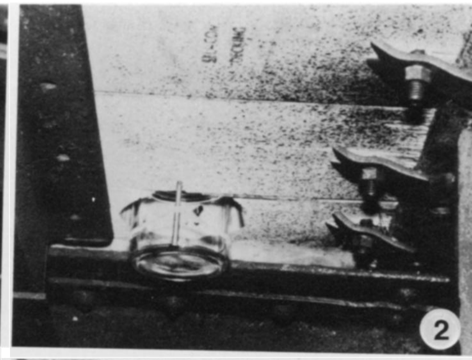
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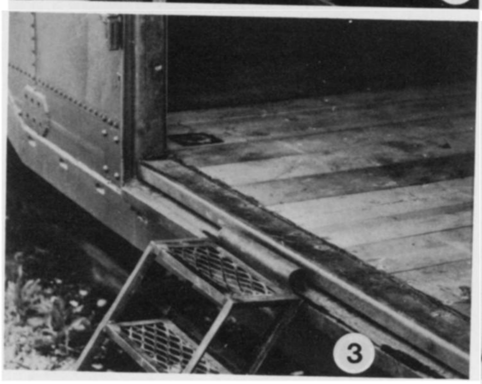
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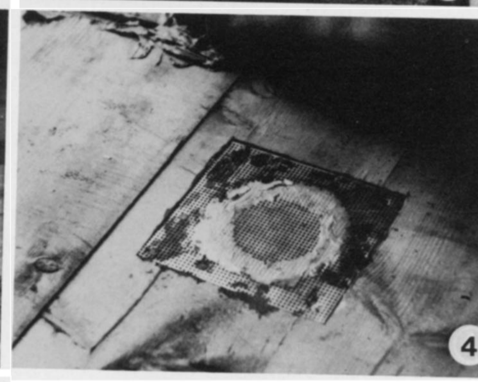
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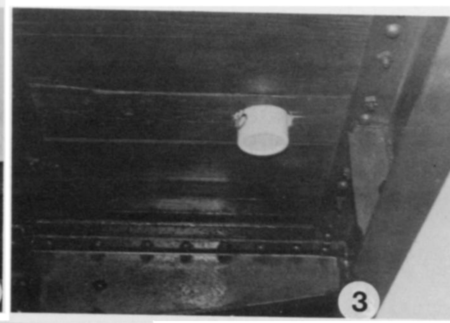
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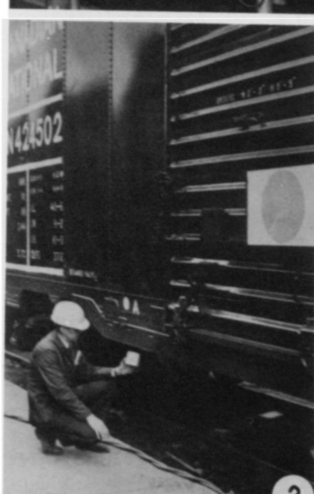
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1 to 3% of all railcars carrying cereals in western Canada using standard grain-sample procedures. If these traps were installed on all grain-transport vehicles, insect infestations could be easily and rapidly checked with greater sensitivity. Another study using probe traps attached to the inside walls of boxcars reported very low numbers of insects captured during wheat transport in Canada (Smith and Loschiavo, 1978).

Development of Probe Traps

The first probe traps to catch insects in stored grain were developed and modified by Loschiavo and Atkinson (1967, 1969, 1973) (Fig. 2). The initial trap was custom-made of heavy-gauge brass and required considerable machining. This trap: a) captured insects yet prevented grain from entering the trap; b) was escape-proof for most species and could be left in grain for long periods to detect even very low insect densities; c) displaced only small volumes of grain and could be used in areas inaccessible to some sampling devices; and d) could be used to capture live specimens of the rarer species. In one test, this trap collected a total of 9200 adults of *C. ferrugineus* and the foreign grain beetle, *Ahasverus advena* (Waltl) in 4 days near a hot-spot in a granary.

The model developed in 1969 was made of less expensive materials and was cheaper to manufacture. Both of these early models had extension pipes attached to them for insertion and removal from grain. Loschiavo and Atkinson (1969) also outlined how farmers could make their own simplified traps by drilling holes in lengths of pipe with a cap at the lower end holding cotton coated with oil to kill the insects.

The model developed in 1969 had some disadvantages such as distortion of the perforated brass cylinder with continuous use beyond 3 m under the grain surface, making subsequent trap assembly difficult. In damp grain, the smooth metal nose cone (collection chamber), and the iron center post rusted allowing insects to escape. Also, large numbers of extension pipes were needed to insert traps at various depths.

The trap developed in 1973 was escape-proof, strong, constructed of rust-proof materials, slimmer, relatively economical, light, compact, and simple to use. Instead of leaving pipes attached to the trap, a threaded pipe was used to position the trap in the grain and a rope attached to the trap remained at the grain surface for trap removal. Loschiavo (1975) tested all three models (Fig. 2) of his trap under a wide variety of field conditions over 3 years and concluded that the 1973 model was the best.

A multi-section probe trap (Fig. 3) was built and tested by White and Loschiavo (1986) to determine the dispersion of *C. ferrugineus* and *T. castaneum* adults and the depths where capture of each species was most likely. Using one central multi-trap in each of nine bins holding 218 kg of wheat, the traps removed 57% of *T. castaneum* adults in 6 weeks at 21–24°C regardless of insect density (1, 2, 10 adults per kg wheat) whereas 23% of *C. ferrugineus* were captured at a density of 10 adults per kg of wheat or 14% were captured at densities of 1 or 5 adults per kg. *T. castaneum* adults were captured more often at the grain surface while *C. ferrugineus* adults were usually captured near the bottom of the bins. At >17°C, 2–3 times as many of both species were captured in traps with wheat germ than in unbaited traps. Traps baited with live adults of both species were no more

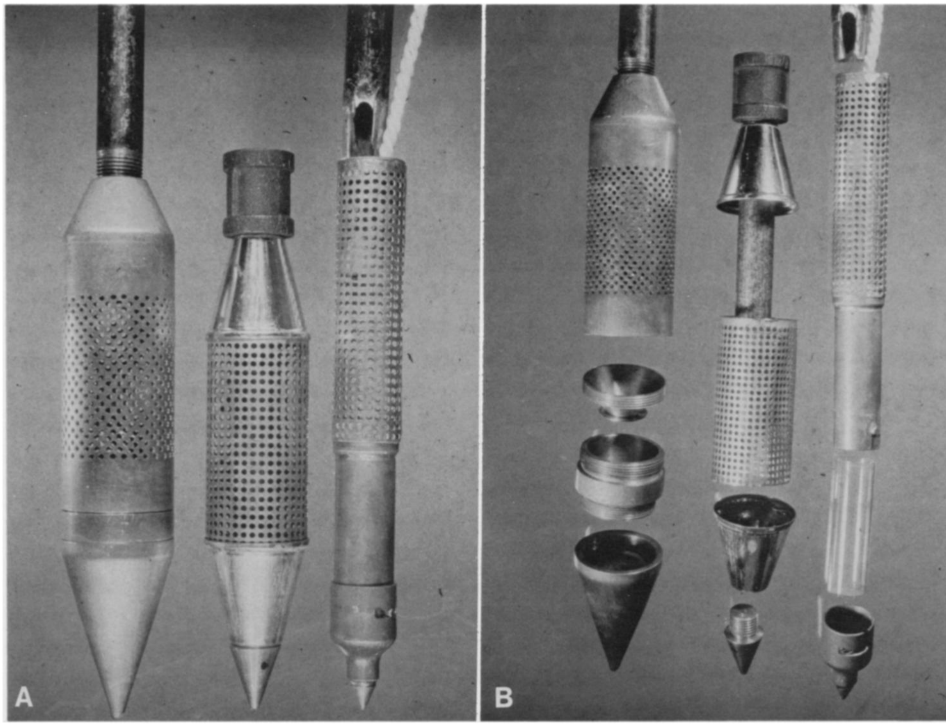

Fig. 2. Assembled (A) and disassembled (B) probe traps developed by Loschiavo and Atkinson (1967, 1969, 1973), left to right.

attractive than unbaited traps. Acclimatized *T. castaneum* and *C. ferrugineus* were collected in low numbers in traps at temperatures as low as 3°C.

White and Loschiavo (1988), using the multi-section trap, reported that *C. ferrugineus* adults were caught in higher numbers in trap sections near pockets of rotting and wet wheat, whereas *T. castaneum* were not attracted to these areas. Dolinski and Loschiavo (1973) and Loschiavo (1974b) also reported that *C. ferrugineus* adults were attracted to moldy grain.

Barak and Harein (1982) modified the trap of Loschiavo and Atkinson (1973) by increasing the perforation diameter to 2.39 mm from 2.16 mm to facilitate the capture of the larger black flour beetle, *Cynaeus angustus* (LeConte), and constructed a threaded point section. Six of these traps were left for 5 days in shelled corn in storage facilities in Minnesota and trap catches were compared with deep-bin cup probe samples of grain. The trap-to-probe detection ratio ranged between 3:1 to 31:1 for adults of *Cryptolestes* spp., *A. advena, T. castaneum,* hairy fungus beetles, *Typhaea stercorea* (L.), *O. surinamensis,* and *C. angustus.* Adults of the rice weevil, *Sitophilus oryzae* (L.) were detected using the traps, but not by extensive probe sampling. However, the authors suggested taking grain samples for quality determinations and to check for internal infestation or insect pupae.

A relatively inexpensive clear plastic trap (Fig. 4B) generally similar to those produced earlier, is currently being manufactured and sold under the tradename Storgard® (Trece Inc., P.O. Box 6278, Salinas, California 93912). This trap is 38 cm long × 2.5 cm diam, with 3.2 mm walls that allow machining of downward

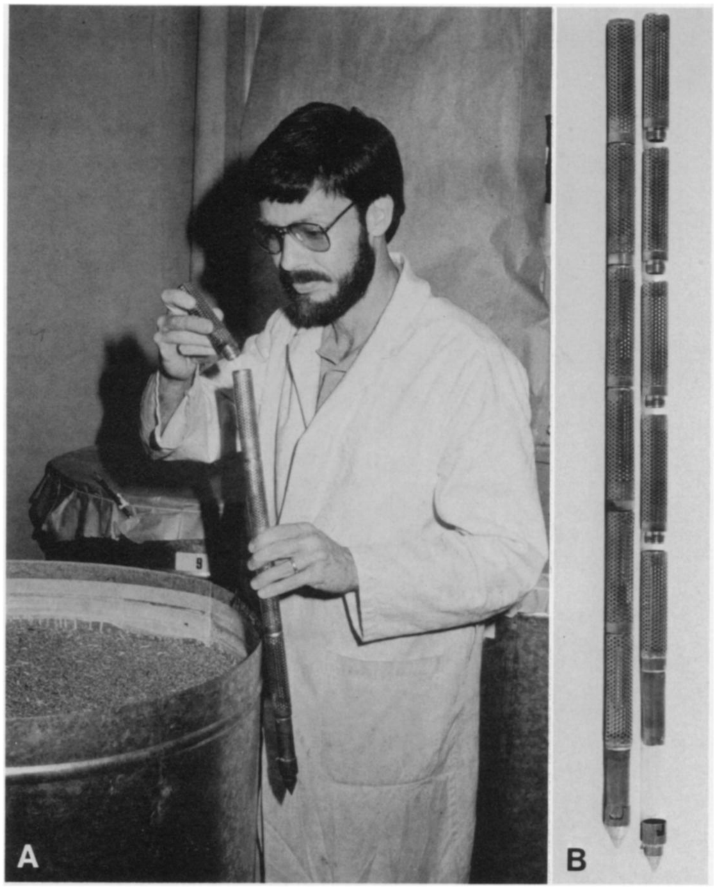

Fig. 3. (A) Disassembling a six-section probe trap with a trapping area that extended from the top of the grain mass to the floor of the bins holding 218 kg of wheat. (B) Assembled and partially disassembled trap.

sloping holes (50°) of 2.79 mm diam. The trap is also available with larger holes (3.79 mm diam) for use in corn (Burkholder, 1984a; Wright and Mills, 1984a). The trap was developed because of a need a) for greater effectiveness of trapping; b) for a larger trap; and c) for easy application of food or pheromones as lures (Burkholder, 1984b). In 1989, a more economical plastic trap with relatively large collecting holes and a tip that acts as a collecting reservoir, was introduced (Storgard® WB Probe II) (Gustafson Inc., P.O. Box 660065, Dallas, Texas 75266-0065).

Subramanyam et al. (1989a) modified plastic traps so that the holes were sloping

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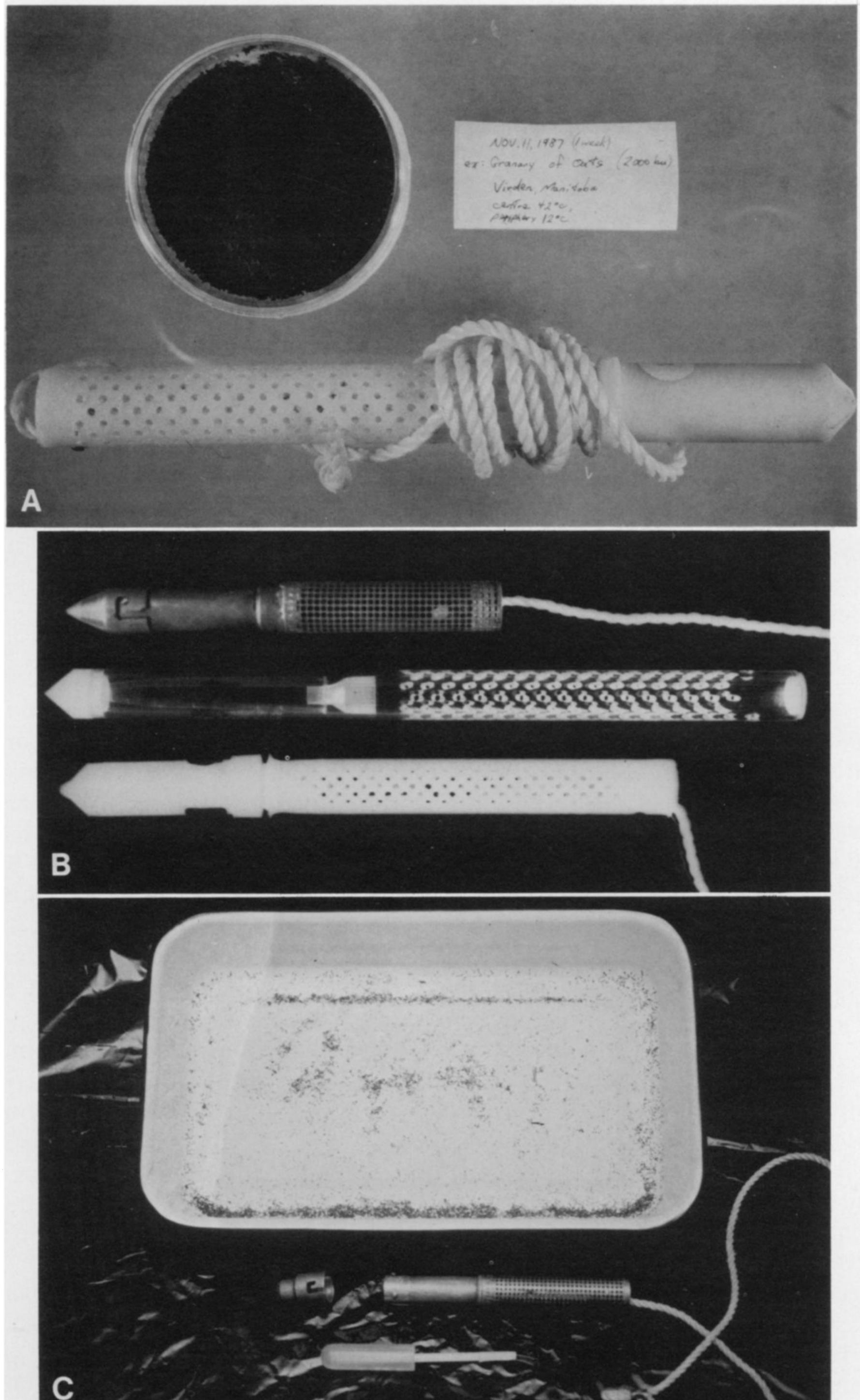
Fig. 4. (A) Approximately 10,000 *Tribolium castaneum* adults collected in a probe trap in 1 week in a hot-spot within a bulk of oats from Virden, Manitoba; (B) Three probe traps—a brass trap (Loschiavo and Atkinson, 1973), a clear plastic trap (Burkholder, 1984a), and a white plastic trap (Madrid et al., 1990). (C) *Cryptolestes ferrugineus* adults collected in 1 week from wheat stored in a grain elevator annex in a brass probe trap baited with *C. ferrugineus* aggregation pheromone (Loschiavo et al., 1986).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Virden, Manitoba
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upwards. This was done to reduce dockage and fines accumulation in traps during insertion or removal from grain. They compared traps with the upward- or downward-sloping holes in the top 16 cm of farm-stored corn, wheat, and barley in Minnesota. Insect species and the number of adults of each species captured by both traps were similar. However, traps with holes sloping upwards collected less whole wheat, barley kernels, or grain debris, making it twice as fast to count and identify trapped insects. Less buildup of dust inside the collecting chamber of traps also may make it harder for some species to escape from the trap.

Another commercial, economical, white plastic trap has been produced by F. J. Madrid in consultation with S. R. Loschiavo, and sold in Canada (Agrobiotech International Inc., 35 Mount Allison Bay, Winnipeg, Manitoba R3T 3L4). This trap (Fig. 4B) has horizontal holes and a screw-on base for collecting insects and appears to work as well as the clear plastic version. All of the probe traps can capture large numbers of adult insects when placed near hot-spots and heavy infestations, where captures of over 10,000 *T. castaneum* or *C. ferrugineus* in 1 week are not unusual (Fig. 4A, C). The potential for regulation of adult numbers by mass trapping has been briefly discussed by White and Loschiavo (1986). Estimates of the number of holes per trap, size of the holes (diam), and total entry area of each of the five traps currently in use are 696, 2.16 mm, 2555 mm^2 (Loschiavo); 432, 2.39 mm, 1938 mm^2 (Barak and Harein); 186, 2.79 mm, 1137 mm^2 (Burkholder); 645, 4 mm × 3 mm, 7740 mm^2 (Storgard WB Probe II); and 408, 3.0 mm, 2884 mm^2 (Madrid).

Wright and Mills (1984a) showed that probe traps captured insects from known populations at different rates in different grains. Corn was particularly poor in yielding insects to traps. By increasing the entry hole size, it was hypothesized that more insects would enter the traps because of the relationship to the larger intergranular spaces in a bulk of corn. Traps with 3.8-mm-diameter entry holes were tested against traps with 2.8-mm holes in bins of 1.3 metric tonnes of corn or 1.5 tonnes of wheat. In different experiments, *Cryptolestes pusillus* (Schonherr), *Tribolium castaneum,* and *Sitophilus oryzae* were released at four densities (0.5, 1.0, 2.0 and 4.0 insects/kg). Paired traps of 2.8- and 3.8-mm holes were placed in the top half of the bins approximately 8 cm below the surface (Wright and Mills, 1984b).

In both wheat and corn, the traps with 3.8-mm entry holes captured more insects. In wheat, 6 times more *Tribolium* were captured at 0.5 insects/kg in 3.8-mm traps than in traps with 2.8-mm holes. Also the numbers of insects captured through the larger diameter hole doubled with each doubling of the population in the bins. The traps with smaller entry holes did not consistently increase captures as the population increased. The disadvantage of the larger entry holes in wheat is an increased amount of grain that falls into the trap making sorting of insects from grain more time consuming.

In corn, *Cryptolestes* was particularly difficult to trap (Wright and Mills, 1984a). At densities of 2.0 and 4.0 insects/kg, traps with 2.8-mm entry holes captured an average of less than 1 insect/trap in 4 days. Traps with 3.8-mm holes not only captured more insects, but also doubled the average trap catch when the population doubled. Because the data were highly variable, many traps and several repetitions (5 traps × 3 bins × 4 dates) were needed to produce these results. Insect behaviour in respect to pitfall traps appears to be different in corn (Wright and Mills, 1984b).

Probe trap (3.8-mm entry hole) captures of *T. castaneum* in corn were compared with numbers of insects in grain samples at densities of 0.5, 1.0, 2.0 and 4.0 insects/kg. The probe trap gave the most reliable estimate of population density. Trier samples gave the actual number of insect/kg at low densities (0.5 and 1.0 insect/kg) but at higher densities (2.0 and 4.0 insects/kg) overestimated the population in an inconsistent manner (Table 1) (Wright and Mills, 1985). The sampling rate was greater than that generally used in on-farm bin surveys in the U.S.A.

Defining Conditions for Effective Use of Probe Traps

Monitoring bulk-stored grain with probe traps can provide meaningful information to guide management decisions on insect control practices and marketing of grain. Proper interpretation of trapping results is dependent on the use of a standard trap design and protocol for sampling. Qualitative information, such as first appearance of insects after harvest (early detection), kinds of insects, locations of aggregations, general population changes over time, and effectiveness of control measures are extremely helpful in the monitoring process.

Such data allow general decisions on pest control to be made within economic guidelines. Insects, such as *Sitophilus* and *Rhyzopertha,* which seriously damage grain, can be dealt with before major problems arise. Increasing or declining populations of external-feeding insects can be monitored for proper use and timing of fumigant application or cold-weather population control. Using traps to detect insects is valuable for evaluating effectiveness of fumigation. Traps can be used to evaluate protectant applications, and monitor insecticide persistence.

Because of the ease of handling probe traps compared to taking grain samples, monitoring is more likely to take place and control measures are more likely to be implemented once insects are seen in the trap. Countries with current low or zero tolerance for insects in export grain may not wish to use probe traps because of the likelihood that grain would be treated with pesticides at very low population densities. However, the probe trap is no less a valuable tool because of our current inability to directly interpret trap captures in unknown bin populations.

The numbers of insects captured in traps are related to species behaviour (aggregation, mobility), grain type, temperature, moisture, duration of trapping period, location and number of traps, as well as insect density (Wright and Mills, 1984a; White and Loschiavo, 1986). The type of storage structure, management practices (aeration, turning of grain), regions of accumulated dockage or general condition of the grain also affect trap catch. Insects are not always uniformly distributed in a bulk of grain (Wright and Mills, 1984b, 1985) and this affects trap efficiency, although grain trier samples (boxcar probes, deep bin cups or torpedo probes) and pitfall cups can be more radically affected.

The use of quantitative data from probe traps to achieve an estimate of population density is difficult. There is still a great deal of work to be accomplished before extension personnel can recommend control measures based on the number of insects in a trap. High numbers of insects in a one-time trapping session may not mean that the grain manager must immediately use control measures.

Several studies have attempted to relate the numbers of insects captured by various techniques to population density. Some compare the number of insects captured with a known population density (Wright and Mills, 1984a, b, 1985). This is the most direct comparison of sampling technique to density. Others compare two sampling techniques to each other in unknown insect densities (Lippert and Hagstrum, 1987; Wright et al., 1990). Comparison of two estimating techniques must be interpreted with an understanding of the possible errors and multiplication of inaccuracies. Estimates can also be made with the assumption that insect distribution is random. As knowledge of insect behaviour increases, this estimate may more often prove inaccurate (Johnston, 1981). Some studies were under controlled conditions in the laboratory while others were in research or farm bins.

When comparing data from probe traps and grain samples, one must recognize the differences between techniques. The grain trier takes an instantaneous sample of grain and insects it contains. The number of insects in the sample is dependent on the grain condition at that time and insect behaviour as it relates to the kind of grain and location of the sample. The probe trap samples only insects and is more heavily dependent on insect behaviour as related to species, temperature, and grain type. The fact that the probe trap remains in the grain for a period of time contributes heavily to the higher numbers caught.

Using five densities of *Cryptolestes pusillus* in 1.5 tonnes of different grains, Wright and Mills (1984a) found that the number of insects in a probe trap was influenced by the type of grain and the location of the trap. At 12 insect/kg, the traps captured a number of insects equivalent to the actual density in three of the four grain types only when placed half-way between the bin wall and the center of the bin. More work is necessary to find whether this relationship is consistent under other conditions. More insects were trapped from sorghum and millet than from wheat. Corn (maize) appeared to change insect behaviour so that significantly fewer insects were captured (5 in corn compared to 11, 19, and 38 in wheat, sorghum, and millet, respectively, in 2 days at 30 ± 2°C). At densities of 2 and 4 insects/kg of wheat only 33% and 67% of grain probes collected *C. pusillus,* but all samples contained adults at 12 insects/kg. Probe traps used at 2, 4, or 12 insects per kg detected insects 56, 89, and 100% of the time in 4 days.

Comparing 265 g samples of wheat and probe trap catches (2-day trapping period) from granaries holding 123–273 tonnes of wheat on 20 Kansas farms, Lippert and Hagstrum (1987) found that traps were 1.7, 2.6, 2.4, and 2.6 times more likely to detect *C. ferrugineus, T. castaneum, O. surinamensis,* and *Rhyzopertha dominica* (F.), respectively, than 265-g grain samples (10 traps, 10 samples per granary taken once). A trap used for 2 days was about twice as likely to detect infestations as a grain sample although at densities of >16 adults per trap this ratio was erratic. Two traps per granary were much more effective than one and little was gained by using more than 10 traps per granary. The equations for estimating the optimal number of traps to determine insect populations in a bin were similar to those Hagstrum (1987) and Hagstrum et al. (1985) used for calculating the optimal number of grain trier samples needed to estimate populations. Generally, a 10-fold increase in sampling intensity increased accuracy of estimates about 3-fold (Hagstrum et al., 1988).

In laboratory studies, Fargo et al. (1989) observed the effects of insect species, grain temperature, and trapping duration on probe trap efficiency. They found more *C. ferrugineus* in traps at 32.2°C than at 10.0°C. The numbers of insects trapped increased with time. *C. ferrugineus* were captured in the greatest numbers followed by *S. oryzae* and *T. castaneum*. *R. dominica* were least likely to be captured.

Loschiavo (1974b) demonstrated that capture of *C. ferrugineus*, at known densities in the laboratory, increased with time, and the number caught was affected by time, population density, location of the trap, position and contour of the trapping surface, size and shape of the container holding the grain, and chemotactic stimuli. More beetles were found in traps baited with rotting grain than in unbaited traps, and males and females were always captured in equal numbers.

Using probe traps 35 cm below the grain surface in a steel granary in Manitoba, Canada, Loschiavo and Smith (1986) found that peak populations of *C. ferrugineus* occurred from late September to mid-October. After November, no beetles were detected until early June. Grain temperatures fell from 15°C in November to −9°C in January and rose to 15°C in June. The number of beetles per trap increased between June and August (range 0 to 315) and increased between August and October (range 91–1212) and then fell rapidly between October and mid-November (range 236 to 2). A large percentage of adults survived −7°C temperatures during the winter.

Although some insects, such as *C. ferrugineus* adults, tend to move downward in columns of wheat with uniform moisture and temperature, they aggregate in any region of grain with higher moisture and temperature (Watters, 1969; Loschiavo, 1983). Loschiavo (1985) demonstrated that post-harvest grain temperature and moisture content were consistently higher at the center of steel granaries than near the periphery. Probe traps detected a variety of insects when inserted 1-m deep at the top center of the bulk but did not detect insects at the outer areas (near bin walls) of the bulk once temperatures began to fall. The most likely place to find insects was in the center of a grain mass near the surface, and the most likely time was 2 months after harvest when insects have multiplied for about two generations.

In a state-wide survey of farm-stored wheat in Kansas (1986), insect infestations were detected with probe traps and grain trier samples (Wright et al., 1990). Both techniques showed lateral insect distribution. Insects were spread over all cardinal points just after harvest with only 27% of the captures from either technique in the center of the bin (Table 2). By September, aggregation at the center position was significant, and remained so until March. In January, 60% of insects collected by the grain trier were in the center of the bin as were 94% of insects collected by probe traps. From grain trier samples taken at three depths, 50% or more of the total insects captured were in the top 60 cm of wheat.

Pheromones and food attractants have been used with probe traps to increase their sensitivity (Burkholder, 1984b). In farm granaries and grain elevator annexes, Loschiavo et al. (1986) compared unbaited probe traps with probe traps containing the aggregation pheromone of *C. ferrugineus*. The standard trapping period was 1 week and numbers of beetles captured in baited traps from annex bins ranged from 0 to 7300. More beetles were found at a depth of 30–60 cm in the wheat than at 150–250 cm. In farm granaries, there usually was no significant difference in trap catches with or without pheromones. Unbaited traps are very effective and pheromones for *C. ferrugineus* would only increase catches at very low insect densities.

Table 2. Distribution of live insects found in probe traps and grain samples from Kansas farm-stored wheat, 1986–1987 (Wright et al., 1990).

		Percent of captured insects							
		Position					Depth		
Sample	Sampling dates	Center	North	West	South	East	Top	Middle	Bottom
Wheat (1000 g)[a]	July	26.7	29.3	0.0	38.8	4.8	31.5	0.0	68.5
	September	40.0**	16.5	14.6	14.5	14.3	54.3**	31.9	13.8
	November	60.3**	9.6	8.6	15.0	6.6	47.9*	34.2	17.9
	January	60.4**	5.2	16.7	5.9	11.7	54.4**	26.0	19.6
	March	69.0	0.0	7.8	11.2	12.1	79.7	8.2	12.1
Traps[b]	July	27.0c	11.1	21.8	21.6	18.5			
	September	39.4bc	13.2	16.0	16.5	14.9**			
	November	67.2b	10.1	5.1	4.8	12.8**			
	January	93.5ab	1.5	1.4	1.4	2.1**			
	March	86.7a	1.2	4.3	4.7	3.1**			

[a] Fifteen samples/bin unless entry difficult or grain depth <2.4 m. Means for center position or top depth differ significantly from other positions or depths at 5% (*) or 1% (**) probability for a given sampling time (row).

[b] Five traps/bin; 4-day trap time; means for center position followed by different letters are significant at 1% probability for sample date (column); center means significantly different from other positions at 1% (**) probability (rows).

Traps must be escape-proof to be effective. However, many stored-product insects, such as *Sitophilus* spp., and *Oryzaephilus* spp., can climb surfaces as smooth as glass. Many researchers (Subramanyam et al., 1989a; Arbogast and Throne, unpubl. data) have noted that dust and dockage accumulates in traps. Dust on the walls of the collection tube may make it easier for insects to escape. In an effort to increase trap catches of the species that could escape the probe trap, Fields (unpubl. data) added cracked wheat which acted as an arrestant; Fluon® (Imperial Chemical Industries, Welwyn Garden City, England) inside the top of the collection chamber, which prevented insects from climbing out; Dri-

Table 3. Percentage of adults escaping from a probe trap during 24 hr. Adults were placed in the collection chamber of a vertical probe trap at 26°C and 50% RH (Fields, unpublished data, 1989).[a]

Material in collection chamber	*Oryzaephilus surinamensis* (L.)	*Sitophilus oryzae* (L.)	*Sitophilus zeamais* Mots.	*Sitophilus granarius* (L.)
Control	41	73	59	3
Cracked wheat	18**	14**	22**	1
Fluon®[b] coating the rim	0**	21**	13**	0
Dri-Die®[c]	0**	0**	0**	0
Mineral oil	0**	0**	0**	0
Peanut oil	0**	0**	0**	0
Malathion-treated[d] cracked wheat	0**	15**	13**	0

[a] $n = 3$; 50 adults per replicate.

[b] Polytetrafluoroethyelene.

[c] 95.4% silicon dioxide, 4.6% ammonium fluosilicate.

[d] 2% active ingredient.

Treatments that are significantly different from the control are indicated by ** ($P < 0.01$), using the Student's t-test.

Table 4. Percentage of adults trapped in a probe trap during an 8-day period. Adults were released into 3.5 liters of red spring wheat of 13.4% moisture content, at 26°C and 50% RH (Fields, unpublished data, 1989).[a]

Material in collection chamber	*Oryzaephilus surinamensis* (L.)	*Sitophilus oryzae* (L.)	*Sitophilus zeamais* Mots.	*Sitophilus granarius* (L.)
Control	12	4	1	5
Cracked wheat	38*	30*	10	5
Fluon®[b] coating the rim	92**	59**	11	15
Dri-Die®[c]	82**	51**	17**	12
Mineral oil	82**	50**	17**	7
Peanut oil	79**	49**	4	16*
Malathion-treated[d] cracked wheat	74**	35**	11	16*

[a] $n = 3$; 50 adults per replicate.

[b] Polytetrafluoroethyelene.

[c] 95.4% silicon dioxide, 4.6% ammonium fluosilicate.

[d] 2% active ingredient.

Treatments that are significantly different from the control are indicated by * ($P < 0.05$) ** ($P < 0.01$), using the Student's t-test.

Die® (silica aerogel, Niagara Chemicals, Burlington, Ontario); mineral oil; peanut oil; or malathion-treated cracked wheat, which killed any insects that fell into the trap. The effectiveness of these treatments was tested by placing insects in the collection chamber of the Madrid plastic probe trap (Fig. 4B) and counting the number that escaped (Table 3), and by placing the probes into wheat with adult insects and comparing the numbers caught after 8 days (Table 2). Untreated traps allowed many insects to escape (Table 3), and trapped very few insects (Table 4). Cracked wheat in the trap increased its effectiveness. But, the greatest catches were in the treatments that killed the captured insects, or prevented their escaping. Similar results were obtained using the clear plastic probe trap (Burkholder 1984a) (Fig. 4B) in wheat infested with *S. orzyae* (Fields, unpublished data). Fluon® coating on the rim or Dri-Die® in the collection chamber doubled trap catches over untreated traps because escape was prevented.

Occasionally encountered when using probe traps in grain-filled steel granaries is the accumulation of water in the collecting chamber of the trap (V. F. Wright, Bh. Subramanyam, F. J. Madrid, pers. obs.). It seems likely that water vapor condensation on the inside of the steel granary roof at night results in water dripping onto the grain surface under humid weather conditions. Moth webbing and pupation cocoons can clog holes in traps placed near the grain surface (Arbogast and Throne; Hillmann, unpubl. data). Traps should not be placed with holes above the grain surface for this reason. If the top of the trap is placed 8 cm below the grain surface, the problem of Indianmeal moth webbing and pupation in entry holes is minimized (V. F. Wright, pers. obs.). Both condensation and moth webbing can best be dealt with by frequent trap inspection.

Experience with Probe Traps

Wright et al. (1988, 1990) surveyed wheat bins on 80 Kansas farms in June and September 1986, and bi-weekly on five farms in 1987 using four kinds of insect traps. More numbers and kinds of insects were found in unbaited probe

Table 5. Detection of live insects by probe traps and grain sampling in Kansas farm-stored wheat, 1986–1987 (Wright et al., 1990).

Sample	Sampling date	Bins infested (%) Trap	Grain sample	Both	Bins apparently not infested (%)	Bins apparently infested (%)
All insects	July	61.5	0.0	15.4	23.1	76.9
	September	15.7	0.0	81.4	2.9	97.1
	November	11.4	11.4	72.7	4.6	95.4
	January	12.5	12.5	37.5	37.5	62.5
	March	32.8	5.3	15.8	42.1	57.9
Rhyzopertha dominica	July	11.5	3.9	0.0	84.6	15.4
	September	15.7	11.4	22.9	50.0	50.0
	November	9.1	29.6	20.5	40.9	59.1
	January	0.0	28.1	3.1	68.8	31.2
	March	0.0	10.5	0.0	89.5	10.5

traps in stored wheat than in grain trier samples. The probe trap findings indicated that large numbers of insects were present in some bins less than 1 month after harvest. Traps indicated that 77% of the bins were already infested in July, the same month that the wheat was harvested, while grain trier samples showed only 15% had insects (Table 5). By September, 97% of the bins were infested to varying degrees according to probe traps. *Rhyzopertha* was not well detected by either technique. In July, traps indicated 11.5% of the new wheat contained *R. dominica* while grain samples showed 4% additional (not the same) bins were infested. In January and March the majority of bins with infestations were detected by grain sampling although insect numbers were small (Table 6). Neither method could be recommended independently for detection of *Rhyzopertha*. Populations in binned grain continued to increase through September. The other three kinds of traps used around the farms indicated a decrease during this period of insects captured from residual grains and feeds.

Subramanyam and Harein (1989) surveyed granaries of barley in Minnesota

Table 6. Mean number of insects in probe traps and grain samples from Kansas farm-stored wheat, 1986–1987 (Wright et al., 1990).

Detection method	Insect	Insects/trap Jul	Sep	Nov	Jan	Mar
Probe trap[a]	*Rhyzopertha*	0.1	4.4	2.0	trace	0.0
	Cryptolestes	3.9	38.3	47.4	4.9	4.5
	Tribolium	0.6	38.8	29.9	7.7	0.3
	Oryzaephilus	5.5	21.3	25.3	2.7	5.5
	Other	0.0	0.7	0.0	trace	trace
Wheat (1000 g)[b]	*Rhyzopertha*	trace	0.3	0.6	0.3	trace
	Cryptolestes	trace	2.2	0.7	0.3	trace
	Tribolium	trace	0.9	2.3	0.9	0.0
	Oryzaephilus	trace	0.5	0.0	0.1	0.1
	Other	trace	0.4	0.5	trace	trace

[a] Five traps/bin; 4-day trap time.

[b] Fifteen samples/bin unless entry difficult or grain depth <2.4 m.

with grain-probing devices and unbaited probe traps in 1985 and 1986. The traps were in place for 30 days and consequently detected more insects than did grain samples. Based on trap catches, 100% of barley bulks were infested with insects. The most common species were *Cryptolestes* spp., *T. castaneum, O. surinamensis, A. advena, R. dominica,* and *T. stercorea.* The Indianmeal moth, *Plodia interpunctella* (Hubner) was rarely seen in grain or probe trap samples.

Arbogast and Throne (unpublished data) compared insects collected in 255-ml corn samples to insects captured in probe traps in three granaries in South Carolina from three to seven months after October, 1986. The grain bulks ranged from 83 to 173 tonnes. Usually two traps were placed in each quadrant of a bin just below the grain surface, and one was placed in each quadrant at the bottom-center of the bins. Twenty-four grain samples were taken throughout each bin on each sampling date. Generally, scarce species were best detected by traps, while moths and parasites were often best detected by grain samples (Table 7).

Hillmann (unpubl. data) used probe traps with and without the aggregation pheromone for *Sitophilus* spp. on farms in North Carolina from November 1986 to July 1987. One baited and one unbaited trap were placed 1 m apart at the center of each bin containing corn to a depth of about 1 m and checked monthly. Five grain trier samples were also taken in each granary on each sampling date. Both baited and unbaited traps captured *Sitophilus, Tribolium castaneum,* and *Cryptolestes* spp. *Stegobium panaceum* (L.) was captured in equal quantities in both types of traps. *T. castaneum* was the most abundant insect, probably because it was malathion resistant. Traps were more sensitive than grain trier samples unless pest levels were high. Generally, the pheromone had little significant effect on species other than *Sitophilus* spp. Monthly checking of traps was too infrequent because insects decomposed as the traps began to fill. Traps at the grain surface or a few centimeters below the surface often became clogged with *P. interpunctella* webbing. This was prevented by insertion to a 1-m depth. Farmers involved in the study were pleased with the trap and inspected their grain more often than previously. One farmer found he did not need a $400 prophylactic fumigation. Most farmers indicated they would be willing to pay $5 to $10 for each trap. At the time, the retail price was about $20.

In a survey of stored wheat, barley, and oats in 106 to 116 granaries in Manitoba, Canada, in the fall of 1986 and summer and fall of 1987, single probe traps were placed in the center of grain bulks, 1 m deep, and were checked after 1 week (Madrid et al., 1990). One or more insects were trapped in 48% of bulks in the fall of 1986, 88% in the summer of 1987, and 85% in the fall of 1987. The most common species were *C. ferrugineus* and *T. castaneum* but the most common group was fungus feeders (Table 8).

Probe traps can also be effectively used to observe the changing pattern of species infestations over the years in geographical areas e.g., *S. oryzae, R. dominica* in western Canada, and differences in *R. dominica* or *P. interpunctella* population levels in two climatic zones in Kansas.

Summary and Conclusions

Probe traps for use in bulk-stored grain are important and versatile tools for detecting insect infestations from very low to high densities. The traps are sensitive for adults of most stored-product insects, and can be relatively economical, and

Table 7. Insects detected (*) by sampling 255 ml corn, sifting and incubating for 4 weeks at 30°C or by probe traps left 1 week in 3 granaries in South Carolina (Arbogast and Throne, unpubl. data).

	Farm 1		Farm 2		Farm 3	
Insect	Sample (n = 240)	Trap (n = 116)	Sample (n = 96)	Trap (n = 56)	Sample (n = 192)	Trap (n = 94)
Hemiptera						
Xylocoris spp.	*	*	*	*	—	*
Coleoptera						
Tenebroides mauritanicus (L.)	—	*	—	—	—	—
Cryptophilus integer (Heer)	—	*	*	*	—	—
Litargus balteatus LeConte	—	*	*	*	—	*
Cryptolestes spp.	*	*	*	*	*	*
Ahasverus advena (Waltl)	*	*	*	*	—	—
Cathartus quadricollis (Guerin-Meneville)	—	—	—	*	—	—
Oryzaephilus surinamensis (L.)	*	*	—	—	—	—
Carpophilus dimidiatus (F.)	*	*	*	*	*	*
Carpophilus hemipterus (L.)	—	—	—	*	—	—
Typhae stercorea (L.)	*	*	*	*	—	*
Tribolium castaneum (Herbst)	*	*	*	*	—	*
Araeceras fasciculatus (DeGeer)	—	—	*	—	—	—
Stegobium paniceum (L.)	—	*	—	—	—	—
Sitophilus spp.	*	*	*	*	*	*
Lepidoptera						
Plodia interpunctella (Hubner)	*	*	*	—	*	*
Cadra cautella (Walker)	*	—	*	—	*	*
Sitotroga cerealella (Oliv.)	*	—	*	—	*	*
Hymenoptera						
Bracon hebetor Say	*	*	*	—	—	—
Anisopteromalus calandrae (Howard)	*	*	*	—	*	—
Choetospila elegans Westwood	*	*	*	—	—	—
Cephalonomia spp.	*	—	—	—	—	—
Holepyris sylvanidis Brethes	—	*	—	—	—	—

Farm 1 (means) = 4.5 insects/liter; 93.5 insects/trap.
Farm 2 (means) = 28.7 insects/liter; 72.4 insects/trap.
Farm 3 (means) = 3.5 insects/liter; 2.5 insects/trap.

are easy to use and inspect. Traps are excellent research tools for studying insect movement, population dynamics, and collecting live insects for experimental use, such as detecting insecticide resistance in field strains (Subramanyam et al., 1989b). Major advantages are that probe traps increase the interest and awareness of farmers and grain managers about the need for grain protection, and the results of trapping can guide early management decisions. Results may indicate that action is not needed, preventing unnecessary prophylactic treatments, or may indicate which kind of treatment—chemical control, aeration, or grain movement—is most appropriate.

There are limitations to effective use of probe traps. Trap sensitivity can be a draw-back if low densities of insects are detected in grain after a chemical treatment

Table 8. Frequency of co-occurrence (%) by predominant arthropods in wheat, barley, and oats stored in 106 granaries in southern Manitoba, Canada in the fall of 1987; n = infested bins; co-occurrence is indicated by column. Results are from single probe traps placed 1-m deep in the center of bins for 1 week (Madrid et al., 1990).

	Granivores		Fungivores				Others			
	Cf (n = 42)	Tc (n = 17)	Ty (n = 34)	Aa (n = 25)	Cc (n = 33)	Psoc (n = 25)	Mites (n = 17)	Xg (n = 9)	Af (n = 14)	Hym (n = 23)
Granivores										
Cf	100	76	59	56	60	60	65	89	1	70
Tc	31	100	24	20	12	8	12	0	14	9
Fungivores										
Ty	48	47	100	60	55	68	41	67	79	52
Aa	33	29	44	100	40	52	41	22	71	30
Cc	50	24	53	56	100	60	53	56	71	48
Psoc	23	12	35	32	30	100	41	33	43	35
Mites	26	12	21	28	27	48	100	33	43	30
Others										
Xg	19	0	18	8	15	12	18	100	21	26
Af	26	12	23	28	21	24	35	33	100	30
Hym	38	12	35	28	33	52	41	67	71	100

Cf = *Cryptolestes ferrugineus* (Stephens), Tc = *Tribolium castaneum* (Herbst), Ty = *Typhaea* sp., Aa = *Ahasverus advena* (Waltl), Cc = *Cartodere constricta* (Gyllenhal), Psoc = *Psocoptera,* Xg = *Xylocoris galactinus* (Fieber), Af = *Anthicus floralis* (L.), Hym = Hymenoptera.

and regulatory agencies demand further control action. However, detection of insects following control measures is an important technique for monitoring the effectiveness of pest control programs. Traps are relatively slow (days to weeks) whereas grain-probe samples are more immediate, although sieving is necessary.

Traps often do not detect insect larvae of many species whereas Berlese funnels can extract larvae from grain in hours. Some traps collect dust and dockage during insertion in the grain which slows sample analysis and permits some species to escape. Some species such as *R. dominica* are not easily detected with probe traps. Unmodified traps are not escape-proof for *Oryzaephilus* spp. and *Sitophilus* spp. but this can be overcome by using Fluon® or a killing agent in the collection chamber. Water may also occasionally collect in the traps and moth webbing can clog the traps at the grain surface. Regular inspection of the traps would help overcome some of these problems.

Trapping methods must be standardized if the data collected by different researchers and grain managers are to be comparable and quantitative. Variables that need to be standardized include trap types, trapping time, trap placement, methods of reporting results, e.g., insects/trap/day; and temperature and moisture effects must be considered. It would also be useful to combine trapping data with grain-sample data for a more complete view of types of insects in the grain because some species are more likely to be captured by one method than by the other (Subramanyam and Harein, 1989). If insect monitoring with probe traps was standardized, it would provide a basis for comparison between studies and provide more reliable information to grain managers.

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